Energy demand analysis for small and medium scale heat users in Rotorua aiming at converting existing heating systems to bioenergy.

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Abstract

The climate in New Zealand is in general warmer than northern European and Scandinavian countries. In particular the solar influx is higher. Despite this, there is significant heat demand for both space and hot water heating in New Zealand. With increasing prices for high quality energy such as fossil fuels and electricity, identification of the specific heat demand that can be meet by lower-grade energies is important in national energy planning. In this paper a survey on heat energy demand in Rotorua schools is evaluated.

The energy systems in the schools older buildings (more than 20 years old) are around two thirds coal centralised hot water heating. Any newer buildings are mainly heated with natural gas or electricity. This means that in general the present centralised heating systems cover less than half of the schools heat demand.

The energy demand profiles have been used as inputs for simulation in the Danish heat plant and cogeneration design model, EnergyPro. By using the model on a school, it is shown that the boilers typically are designed to deliver the heat within the four hours from 6 to 10 am. This means that boilers are typically 4-5 times larger when compared to centralised heating systems with constant heat production and use of heat storage.

From a sustainability perspective, bioenergy based boilers using wood pellets or wood chips, are able to deliver fuel to the schools, which is competitive in convenience, cost, and the environment. Implementing centralised heating systems using heat storage that would cover the whole low-grade heat demand would make bioenergy systems an optimal solution for schools. For New Zealand it would reduce electricity consumption, increase the total efficiency of the energy sector, and reduce the emission of greenhouse gases.

Introduction

The electricity industry in New Zealand has historically played a strong role in providing energy to all sectors of society. The electricity has in many cases been so cheap that it is competitive to any other form of energy carrier or energy source, even for covering low-grade heat demand such as space and water heating. This has made it very difficult for other technologies to be adopted, in particular boilers and solar water heating systems. Log burners have been accepted at the residential level for space heating, but bioenergy systems have not in any way been able to cover any institutional or industrial heat demand. Secondly it makes it very difficult for industries outside the traditional electricity sector to play a role in the electricity market. For instance, wood processing industries converting their boilers to cogeneration for their own electricity and for selling to the grid is not attractive. The simple focus on electricity as the main energy carrier makes it hard for bioenergy to compete, because biomass is not the best fuel for electricity production. The focus in this paper is on the benefit of small to medium scale bioenergy systems to provide heat for the institutional market (i.e. schools).

Energy grade optimisation

Electricity is a high-grade energy form, which can be used by electric appliance with essentially 100% efficiency. However, in the case where the electricity is produced in a thermal conversion process only around 30-40% of the primary energy in the fuel is converted into electricity. If a primary energy source is converted into heat this can be done with 80-90% efficiency. This difference between the conversion efficiency is obviously very significant. Therefore it does not make sense to use high-grade electricity which is produced at a 30-40% efficiency to cover a low-grade heat demand (space heating and hot water heating) where conversion efficiency of 80-90% is easily obtained.

By covering low-grade heat demand with a 90% conversion efficiency, the energy system becomes 3 times more efficient than providing the low-grade heat with electricity from fossil fuels. Another way of comparing this is: 1.5 kg of wood pellets in energy content is similar to 1 kg of coal, but by replacing electricity generated by coal 1.5 kg of wood pellets replaces 3 kg of coal. It should in this case be mentioned that heat pumps are able to produce low-grade heat with 250% efficiency, which means that if electricity is used for space heating it only makes sense with heat pumps.

Figure 1 illustrates an energy management hierarchy in an attempt to address the issues raised above. The waste management paradigm (left column of Figure 1) was developed for the New Zealand Waste Minimisation Strategy (Ministry for the Environment, 2002). A similar paradigm for the energy sector is given on the right side of Figure 1. As with waste management, reduction in the consumption and waste of energy “energy savings” is the main target. This can be achieved by carefully evaluating the energy demand. Energy savings are typically divided between the energy efficiency options and energy conservation options, but this distinction has not been made in Figure 1. This is all good for a sustainable energy sector. It is about use of energy efficient end-use technologies (refrigerators, lamps etc.) and avoiding wasteful use of energy, for instance turning lights off when you are not in the room.

Through energy grade optimisation low-grade energy sources should cover low-grade heat demand. Which means that it is wasteful to use electricity for space and water heating, when it can be provided efficiently with a "low grade energy source".

At the third level, combined heat and power production is the first choice of converting a primary fuel into energy (i.e. electricity and heat). In this case a cogeneration system can provide 25-35% electric efficiency and at the same time provide a 40-50% low-grade heat efficiency. In this case a total efficiency of 60-70%. When generating both heat and power the total efficiency is lower than the total efficiency if the fuel was only converted into heat (total efficiency down by 10-20%). But the electricity achieved has a higher value for us. Looking at this step isolated, any cogeneration is good, whether it is biomass or a fossil fuel. Finally, at level 4 in the hierarchy, fuel can be switched from fossil fuels to a renewable source, like biomass.

Increasingly sophisticated tiers are contained in each level, so Figure 1 is only meant as an illustration, of how to approach a "solution" in a sustainable energy sector.

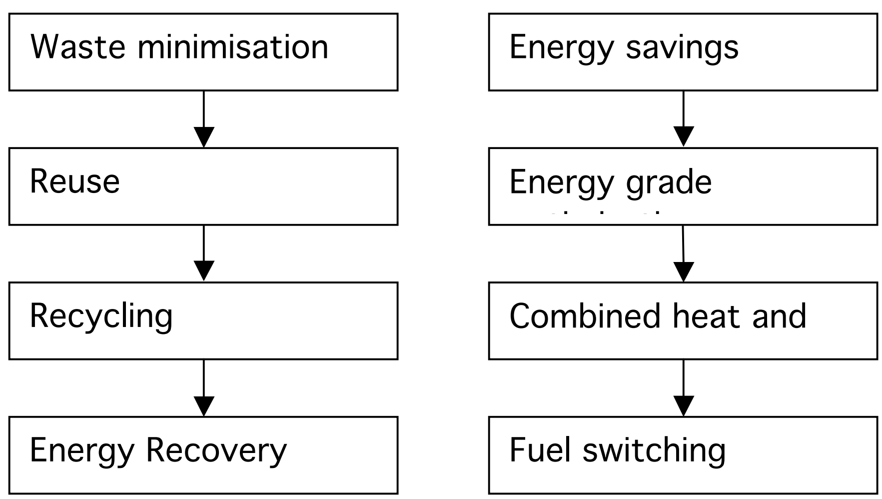

Figure 1: The waste hierarchy with a suggestion for similar energy hierarchy.

In the following a survey on energy use in schools has been carried out. At this initial stage for identifying the low-grade heat demand. The survey was carried out in 2003/2004 in Rotorua and covers all 27 schools in Rotorua.

Energy use at schools

- energy demand

Energy demand in a school can typically be divided between space heating, water heating and electricity. Energy use in a school is typically not of concern, the costs are included in the school budget, but otherwise in the practical hands of the caretaker and thereafter only considered when the heating is not working or there is a power cut. The general impression after carrying out the survey on the schools is that the caretakers are very happy to discuss the energy issues, as it is part of their responsibility.

- electricity demand

Typically a school does not have a high electricity demand, or in other words a school does not have heavy electricity using machines. A school has electricity demand for lighting, computers and refrigeration. In general terms a significant part of the electricity consumption is used for low grade energy purposes like space heating and water heating. In this study the electricity demand has not been studied in more detail. The focus has been on identifying and evaluating space and water heating demand.

- water heating demand

Unless heating a swimming pool a typical primary school does not have a significant hot water demand. At the High schools their physical education program creates a need for showers in their gymnasiums. This is one reason why secondary schools in general have a higher total energy demand per student than the primary schools. With regard to water heating for swimming pools, only one quarter of primary schools heat their swimming pools.

- Space heating demand

There is a space heating demand during winter. School buildings are typically old and, not very well insulated with single layer glazing. The way schools are working probably makes this acceptable. The big classrooms create activities and a need for ventilation, which can easily be met by opening windows and for flow between outdoors areas and between classrooms. There is typically no heat demand after 10 am in winter.

By interviewing the caretakers a general daily, weekly and annual heating profile has been determined.

- annual profile

There is only a heat demand during the coldest 5 months of the year.

- weekly profile

During the heating season the schools will only be heated during the school days.

- daily profile

During the school days the heat will be on from around 6 am to 10 am. The heating systems are typically designed to be able to heat the school in a few hours and after around 10 am the outdoor temperature has increased sufficiently to turn off the heating system. Whether there is a heating demand during the day will then depend on the buildings orientation towards the sun.

- cooling demand

In some of the schools, heat pumps are installed in new buildings or retrofitted during building renovations. This is a more efficient way of providing heat than standard electric appliances and it also provides cooling during summer. This is convenient, but should also be seen as a new energy service to the schools, and could mean that the heat pump is not saving electricity for the school.

Survey method

All 27 schools in Rotorua were surveyed by personal visits to the schools for the completion of a questionnaire. The first point of contact for completion of the questionnaire was the Caretaker of the school. The collection of annual cost data usually required contact with school management.

The data collected included the school size, building type, layout, age, type of heating used, amount of energy used, costs of energy use, problems with current heating technology and future plans for heating. If parts of the questionnaire were unable to be completed the assumptions were applied to the data that was collected to fill the relevant gaps.

Results

The schools had a 5-month heating season on average, which resulted in heating being 40-50 % of the schools total energy costs. One quarter of the schools also heated swimming pools to extend the swimming season for their students.

45% of Rotorua's schools use coal for space heating in some of their rooms, with the typical pattern being coal in the older classrooms built at the establishment of the school, and electricity in any additional prefabs. These coal boilers usually run at full output 4 to 5 hours per day, and then idle the rest of the day, as there is no heat storage capacity available in the systems. This idling phase is inefficient, and adds to the system being more polluting.

Running non-centralised electric heating in prefabs cost the schools at least 3 times the amount in energy costs for the same area as their centralised coal heating.

In generating the energy demand discussed below the following assumptions have been used:

- Calorific value of coal = 26 GJ/t
- Caloric value of pellets = 18 GJ/t
- Cost of coal delivered = $160/t
- Cost of natural gas = $12 GJ
- Cost of electricity = $0.14/kWh
- Allocation of electricity for heating is 50% of the annual bill for schools were electricity is the dominant energy source
- Efficiency of coal boilers = 70%
- Efficiency of Pellet boilers = 80%
- Efficiency of Gas boilers = 90%
- Efficiency of electric heaters = 100% (no generation losses taken into account)

In Figure 2 the energy sources used for heating is illustrated. It shows that gas is a slightly more popular energy source then coal, followed by electricity and Geothermal. Only two schools are using geothermal energy to meet some of their heat demand. As mentioned above some of the heat demand in the schools using coal and natural gas is met by electricity as the secondary energy source.

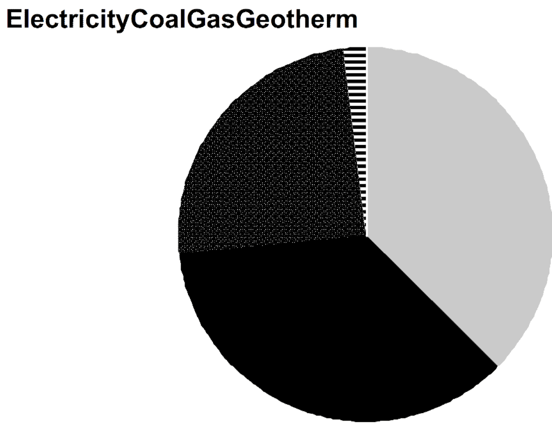

Figure 2: Illustrates the percentage of schools using the various energy sources

The schools cost of energy in $/kWh of heat delivered is illustrated in figure 3. If required by incomplete data, the calculation was made on the assumptions listed above. Although some of the assumptions may contribute to the pattern illustrated, the results are clear. The schools using electricity for their heat demand have the most expensive energy, followed by natural gas, coal and geothermal.

Figure 4 shows that unlike $/kWh, the $/student for heat energy costs is not related to the dominant energy type used. It is likely to be a function of class size, building type and age, and whether a swimming pool is being heated. The individual school's "energy policy" may also play a role, which may be decided by the caretaker or the principal and be independent on the energy fuel used.

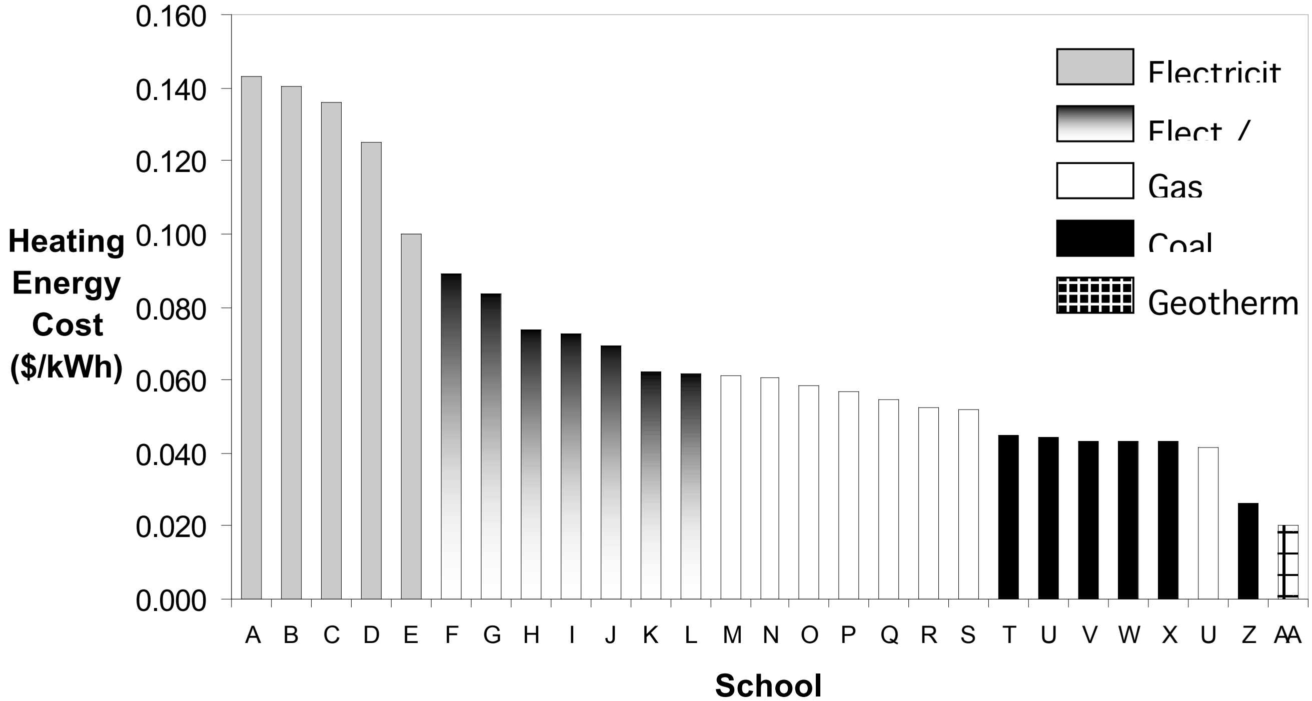

Figure 3: Average cost $/kWh per Rotorua school (heat demand only)

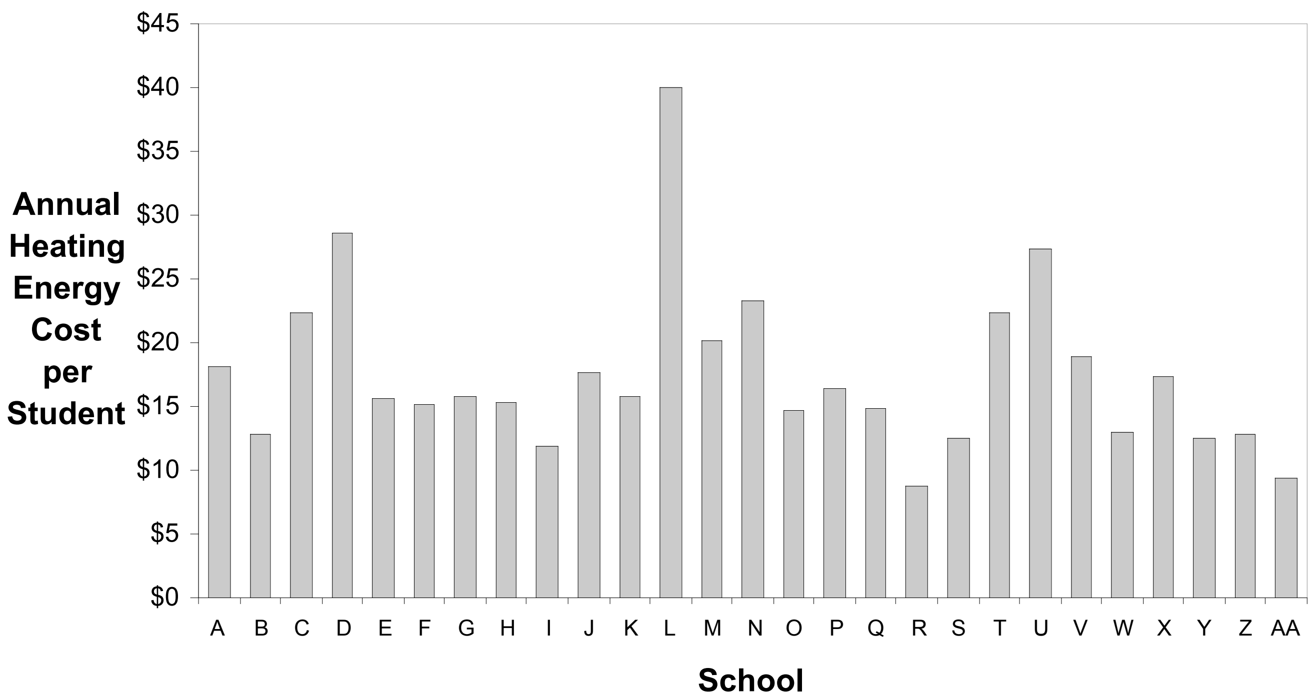

Figure 4: Annual Heating Energy cost per student of each school (heat demand only)

EnergyPRO evaluation

As described above, the schools typically during winter are heating the building from 6 to 10 am. The energy demand profiles have been used as inputs for simulation in the Danish heat plant and cogeneration plant design model, EnergyPRO (EMD.DK, 2004). It is a complete software package for the design, optimisation and analysis of energy projects. The software is designed to cater for a wide range of technologies including cogeneration of heat and power (gas engines, gas turbines, steam boiler systems), tri generation systems incorporating absorption chillers, as well as auxiliary systems such as thermal storage and limited fuel storage. The user is able to input a wide range of data on different energy plant types, external conditions such and energy demand profiles, and weather data. The main data necessary is the daily, weekly and annual energy profile and total annual consumption.

Using data from one school, the daily operation during a winter week is illustrated in Figure 4. It shows that the boilers typically are designed to deliver the heat within the four hours from 6 to 10 am, which is the peak occurring every day. The other flatter graph is an assumed energy system using only 25% of the existing boiler capacity, but including heat storage. In this case a smaller boiler or boilers would run on full capacity almost continuously to fill up the heat storage (hot water). When there is a heat demand in the morning, the heat is taken from the heat storage and not from the boiler itself.

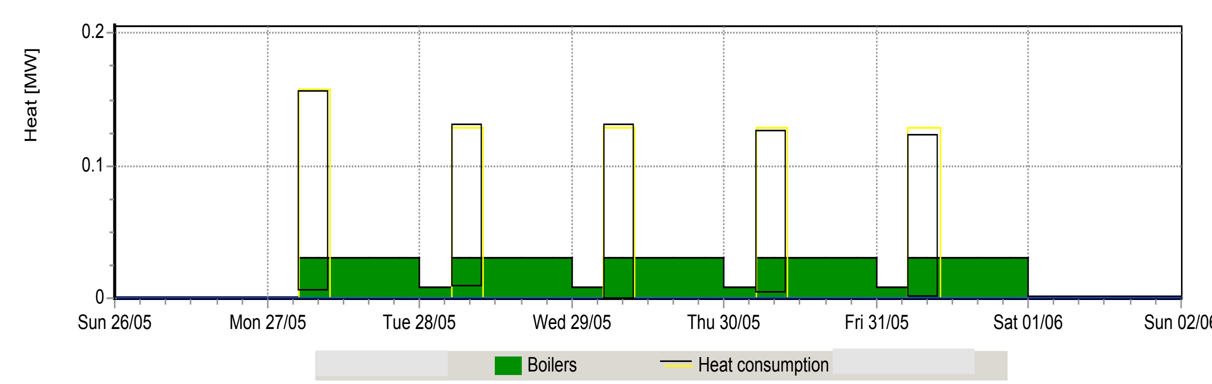

Figure 4: Illustration of heat consumption and boiler output using heat storage at a primary school.

Discussion

The school survey shows a strong trend away from using coal for heating over the last ten years. Any expansion or upgrades in school buildings was used as an opportunity to switch to gas or electricity. This pattern will continue with some of the schools planning now for changes in the medium term to their heating technology. With an uncertain long-term supply of natural gas, the prevalence of computers in the classroom, and climate change making weather patterns more variable, electric heat pumps are the current technology of choice, as they provide efficient and convenient, heating and cooling. And due to the detrimental nature of coal, the trend away from coal will continue.

By understanding energy grade optimisation it is quite obvious that using electricity for heating is inefficient for society. However it may look like a good solution for schools because of the low capital investment of radiant electric heaters.

Heat pumps are a more efficient use of electricity, but they still put pressure on the electricity sector at the time between 6 and 10 am when the electricity demand peaks in winter. The heat pumps use for cooling during afternoon in the summer is not such an issue for the electricity sector.

Almost half of Rotorua's schools still use coal, all the caretakers and principals contacted expressed dissatisfaction with coal on health, environmental, variable quality, and age of system grounds. Consequently positive responses to wood pellets as an alternative to coal were received from these schools. Not that there is a market for a more institutional or industrial use of pellets yet, no pellet burners, no boilers and no advanced systems using heat storage. It is however likely to change in the near future, with increasing prices of fossil fuels and electricity making new wood pellet manufacturing plants more competitive.

One interesting question to ask could be why it was common to install centralised heating systems at the time when most of these schools were built, as there wasn't the same focus on sustainable energy or energy efficiency? Was it because that was the conventional solution at that time? This is the most likely case along with the fact that they were installed at the construction of the school and the cost was being met completely by the Government. Today however a schools funding enables it to meet their operational costs i.e. energy bills, but does not allow significant capital expenditure on upgrades. Thus with expansion of the school, low capital, and higher operational cost electric heaters were chosen rather than expanding centralised heating. The decision to change energy sources by a school is therefore not because new buildings are so much better insulated that they change the economics of heating systems. As most additional buildings over the past few decades have been prefabricated, which are less well insulated than the existing buildings. The way schools are funded has a significant bearing on the current and future energy technologies they employ.

At the current residential price of wood pellets, 0.08 $/kWh of heat delivered, wood pellets would compete on energy price with schools on electrical heating, and will be able to compete on environmental grounds with coal. At a bulk commercial price of 0.06 $/kWh of heat delivered, wood pellets would compete on energy price with schools on electrical, elect/coal, and gas heating and will be able to compete more closely with coal on price and with their added environmental benefits. These costs do, however, not include the capital investment. Capital investment of these new systems will be further researched in the next year.

Conclusion

With increasing prices for high quality energy such as fossil fuels and electricity, identification of the specific heat demand that can be met by lower-grade energies is important in national energy planning. An energy management hierarchy has been developed to illustrate the importance of utilising limited fossil fuel resources and the renewable energy resources optimally.

In this paper a survey on heat energy demand in Rotorua schools was evaluated. The energy systems in the schools older buildings (more than 20 years old) are around two thirds coal centralised hot water heating. Any newer buildings are mainly heated with natural gas or electricity. This means that in general the present centralised heating systems cover less than half of the schools heat demand. So in many ways the schools have gone down the track of either using electricity entirely for heating at the school or using electricity for heating in new buildings, which is not an energy efficient solution. Only in the cases where heat pumps have been installed can the solution be regarded to be "sustainable".

The energy demand profiles have been used as inputs for simulation in the Danish heat plant and cogeneration design model, EnergyPro. By using the model at a school, it is shown that the boilers typically are designed to deliver the heat within the four hours from 6 to 10 am. This means that boilers are typically 4-5 times larger when compared to centralised heating systems with constant heat production and use of heat storage. This means in many cases the boiler systems are big enough to provide centralised heating for the whole school, if heat storage is incorporated.

From a sustainability perspective, bioenergy based boilers using wood pellets or wood chips, are able to deliver fuel to the schools, which is competitive in convenience, cost, and the environment. Implementing centralised heating systems using heat storage that would cover the whole low-grade heat demand would make bioenergy systems an optimal solution for schools. For New Zealand it would reduce electricity consumption, increase the total efficiency of the energy sector, and reduce the emission of greenhouse gases.

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